Journal of Dental Sciences (2014) 9, 364–370

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.e-jds.com

ORIGINAL ARTICLE

Effects of different light sources on microleakage of composite resins with different monomer structures†

Fikret Yilmaz [a], Nihan Gonulol [a], Eda Guler [a*], Engin Ersoz [b], Fatma Aytac [b]

[a] *Department of Restorative Dentistry, Faculty of Dentistry, Ondokuz Mayıs University, Samsun, Turkey*
[b] *Department of Restorative Dentistry, Faculty of Dentistry, Ankara University, Ankara, Turkey*

Received 26 December 2011; Final revision received 4 November 2012
Available online 30 May 2013

KEYWORDS
light curing units;
microleakage;
silorane-based composites

Abstract *Background/purpose:* The aim of this study was to investigate the effects of different light curing units (LCUs) on the microleakage of different composite resins.
Materials and methods: Forty-five freshly extracted human third molars were selected for this study. Standardized class V cavities were prepared on the buccal and lingual surfaces of each tooth. The teeth were randomly divided into three composite resin groups, comprising two dimethacrylate-based hybrid composites and a silorane-based composite. Each composite resin group was randomly divided into three subgroups for curing with three different LCUs ($n = 5$). Of the three different LCUs used, one was quartz–tungsten–halogen and two were light-emitting diodes (LEDs) with different power outputs. The teeth were immersed in a 2% methylene blue dye solution and examined under a stereomicroscope. Results were statistically analyzed using Kruskal–Wallis and Dunn tests.
Results: When all composite resin groups were compared, the lowest marginal leakage scores were obtained with the Filtek Silorane composite group, and they statistically significantly differed from those of the other groups ($P < 0.05$). Among all groups, the lowest marginal leakage value was obtained for the LED 1055 subgroup of the Filtek Silorane composite group, and the highest marginal leakage value was obtained for the quartz–tungsten–halogen subgroup of the Aelite Aesthetic Enamel composite group.
Conclusion: It was concluded that it is not possible to entirely prevent microleakage, but it can be minimized with silorane-based composite resins and high-density-output LED LCUs.

* *Corresponding author*. Department of Restorative Dentistry, Dental Faculty, Ondokuz Mayıs University, Kurupelit, Samsun 55139, Turkey.
E-mail address: edaguler@omu.edu.tr (E. Guler).
† This study was presented as a poster at Conseuro 2009 in Seville, Spain in March 2009.

1991-7902/$36
http://dx.doi.org/10.1016/j.jds.2013.01.009

Introduction

Two major properties of dental composites that still need improvement are their polymerization shrinkage and the related polymerization stress. Both parameters contribute to different clinical challenges such as reduced marginal integrity and postoperative sensitivity.[1] To overcome these shrinkage-induced problems, extensive efforts have been made over several years to develop low-shrinkage dental restorative materials.[2] The most recent one is based on using ring-opening polymerization of silorane molecules, instead of free radical polymerization of dimethacrylate monomers. The term "silorane" was introduced to represent hybrid monomer systems that contain both siloxane and oxirane structural moieties. Concerning the material properties of siloranes, the cyclosiloxane backbone imparts hydrophobicity, whereas the cycloaliphatic oxirane sites have high reactivity and shrink less during polymerization than methacrylates. Some cyclosiloxanes were reported to undergo cationic ring-opening polymerization with volume expansion.[3] This novel resin is considered to have combined the two key advantages of individual components: low shrinkage due to the ring-opening oxirane monomer and increased hydrophobicity due to the presence of siloxane species.[1]

Until recently, light emitted from a halogen light bulb was used to cure composites. These types of curing units usually operate at light intensities of 400–800 mW/cm^2 and cure composite filling material within 40 seconds.[4]

Solid-state light-emitting diode (LED) technology was proposed in 1995 for the polymerization of light-cured dental materials to overcome the shortcomings of halogen visible light curing units (LCUs).[5] LEDs use junctions of doped semiconductors to generate light instead of the hot filaments used in halogen bulbs.[6] LEDs have a lifetime of more than 104 hours and undergo little degradation of output over time. LEDs require no filters to produce blue light, are resistant to shock and vibration, and use little power to operate.[5]

The purpose of this study was to compare the microleakage of three different composite resins, two of which have dimethacrylate monomer structures (Aelite Aesthetic Enamel and Inten-S) and one with a silorane monomer structure (Filtek Silorane) after polymerization with three different LCUs.

The first null hypothesis to be tested was that microleakage values of silorane-based composite resins would be lower than those of methacrylate composite resins. The second null hypothesis was that there would be no differences in microleakage values of composite resin restorations after polymerization with different LCUs.

Materials and methods

Forty-five caries-free, freshly extracted human third molars were selected for this study.

These teeth were extracted because of indications of pericoronitis or periodontitis, or orthodontic or prosthetic treatment reasons from 35 patients. Informed consent was received from all patients. The teeth were stored for less than 2 months in 0.5% chloramine T. Standardized class V cavities (3 mm occlusal–gingival, 3 mm mesial–distal, and 1.5 mm deep) (Fig. 1) were prepared on the buccal and lingual surfaces of each tooth using cylindrical diamond burs with a high-speed handpiece under water cooling. This resulted in the creation of 90 total class V cavities (45 buccal and 45 lingual) on the 45 teeth. The occlusal margin was located 1.5 mm coronal from the cementoenamel junction, and the gingival margin was located 1.5 mm apical from the cementoenamel junction. The same operator prepared all specimens. The teeth were randomly divided into three groups according to the type of composite resin used for restoring the preparations. After that, each composite resin group was randomly divided into three subgroups for curing with three different LCUs ($n = 5$).

In this study, two dimethacrylate-based, same-shade (A2) hybrid composites [Aelite Aesthetic Enamel (BISCO, Schaumburg, IL, USA) and InTen-S (Ivoclar-Vivadent, Schaan, Lichtenstein)], and a silorane-based composite (Filtek Silorane; 3M/ESPE, St. Paul, MN, USA) were used. Clearfil S^3 bond (Kuraray, Okayama, Japan) was applied to the cavities before they were restored with the dimethacrylate-based composites, and Silorane System Adhesive (3M/ESPE) was applied to cavities before they were restored with the silorane-based composite according to the manufacturers' recommendations. The properties of the resin composite materials and adhesive systems used in the study are respectively shown in Tables 1 and 2.

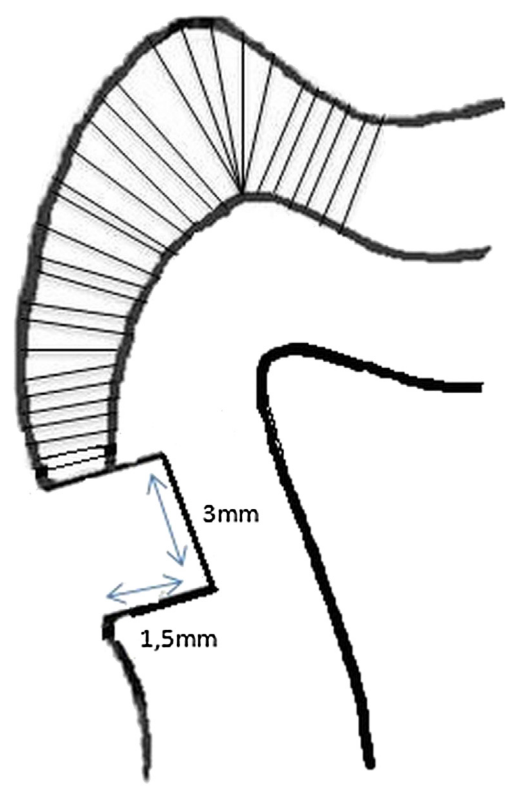

Figure 1 Schematic view of cavity configuration.

Table 1 Properties and manufacturers of composite resins.

Composite resin	Particle size (μm)	Inorganic filler ratio (by weight)	Composition	Manufacturer
Aelite Aesthetic Enamel	0.04—0.5	73%	Bis-GMA, Bis EMA	BISCO, Schaumburg, IL, USA
InTen-S	0.2—7.0	74%	Bis-GMA, BisEMA, UDMA	Ivoclar-Vivadent, Schaan, Lichtenstein
Filtek Silorane	0.1—2	76%	Silorane	3M/ESPE, St. Paul, MN, USA

EMA = ethylenemethacrylate; GMA = glycidylmethacrylate; UDMA = urethane dimethacrylate.

To polymerize the composite resins that were inserted in the cavities, three different LCUs were used, one of which was quartz—tungsten—halogen (QTH) and two of which were LEDs, with different power outputs. The properties and manufacturers of the LCUs are listed in Table 3.

After polymerization of the restorations, all surfaces were sequentially polished with coarse, medium, fine, and superfine Sof-Lex disks (3M/ESPE) with a low-speed handpiece without water coolant spray. Each step of the polishing procedure was performed for 15 s. Root apices were sealed with wax to avoid dye penetration from the root canal.

Specimens were thermo-cycled for 1500 cycles at 5—55°C (DTS B1; Dentester, Salubris Technica, Istanbul, Turkey), with a dwell time of 10 seconds in each water bath. Subsequently, the teeth were covered with two coats of nail varnish. All areas of the teeth were covered with the varnish except for the restorations and 1 mm around each restoration. The teeth were immersed in a 2% methylene blue dye solution for 24 hours at 37°C, rinsed in tap water for 1 hour, and sectioned in the buccolingual plane through the center of the restorations with a water-cooled diamond saw (Isomet 1000; Buehler, Lake Bluff, IL, USA), thus obtaining two sections for each restoration. Both the buccal and lingual surfaces of each section of a tooth were examined under a stereomicroscope (Nikon SMZ 1500; Nikon, Tokyo, Japan) at 25× magnification. Dye-penetration scores are illustrated in Fig. 2A—F.

Measurements were performed by two operators who were blinded to the specimen preparation. The evaluation was performed according to scores listed in Table 4. The deepest microleakage score was recorded regardless of whether it occurred on the gingival or occlusal margin. The results were statistically analyzed using Kruskal—Wallis and Dunn tests.

Results

When all composite resin groups were compared, the lowest marginal leakage scores were obtained with the Filtek Silorane composite group, and those values statistically significantly differed from the other groups ($P < 0.05$).

In the Aelite Aesthetic Enamel composite group, no statistically significant differences were obtained in marginal leakage scores of samples cured with the LED 550, LED 1055, and QTH LCUs ($P > 0.05$).

In the InTen-S composite group, there were no statistically significant differences in marginal leakage scores of samples cured with the LED 550, LED 1055, and QTH LCUs ($P > 0.05$).

In the Filtek Silorane composite group, the lowest marginal leakage values were obtained for the LED 1055 group, and there was no statistically significant difference between this group and the LED 550 group ($P > 0.05$). Although the difference between the LED 550 and QTH groups was not statistically significant ($P > 0.05$), the difference between the LED 1055 and QTH groups was statistically significant, and QTH scores were significantly higher ($P < 0.05$).

Among all groups, the lowest marginal leakage value was obtained in the LED 1055 subgroup of the Filtek Silorane composite group, and the highest marginal leakage value was obtained in the QTH subgroup of the Aelite Aesthetic Enamel composite group (Table 5, Fig. 3).

Table 2 Properties and manufacturers of the adhesive systems.

Adhesive system	Composition	Application protocol	Manufacturer
Clearfil S^3 bond (self-etching, one-bottle bonding agent)	MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate	Apply bond to cavity walls and leave it in place for 20 s, blow high-pressure air for more than 5 s, light-cure for 10 s	Kuraray, Okayama, Japan
Silorane System Adhesive (self-etching primer and bond)	TEGDMA, phosphoric acid methacryloxyhexylesters, 1,6-hexanediol dimethacrylate	Apply primer to cavity and massage over the area for 15 s, blow a gentle stream of air and cure for 10 s, apply the bond to the cavity, use gentle stream of air, and cure for 10 s	3M ESPE, St. Paul, MN, USA

GMA = glycidylmethacrylate; HEMA = hydroxyethyl methacrylate; MDP = methacryloyloxydecyl dihydrogen phosphate; TEGDMA = triethylene glycol dimethacrylate.

Table 3 Properties and manufacturers of the light-curing units (LCUs).

Type of LCUs	Manufacturer	Power of the light source (mW/cm2)	Polymerization mode and time
Light-emitting diode (LED)	Hilux Led-max 1055 (Benlioğlu Dental, Ankara, Turkey)	1300	Standard polymerization 20 s
LED	Hilux Led-max 550 (Benlioğlu Dental, Ankara, Turkey)	500	Standard polymerization 40 s
Quartz—tungsten—halogen	Smart-Lite (Benlioğlu Dental, Ankara, Turkey)	400	Standard polymerization 40 s

Discussion

There are many different techniques to assess microleakage around dental restorations. The easiest and most commonly used methodology involves exposure of a sample to a dye solution and then viewing the cross sections under a light microscope.[7] Dye penetration was chosen in this study because it provides a simple, cheap, quantitative, and comparable method of evaluating the performance of the various restorations.

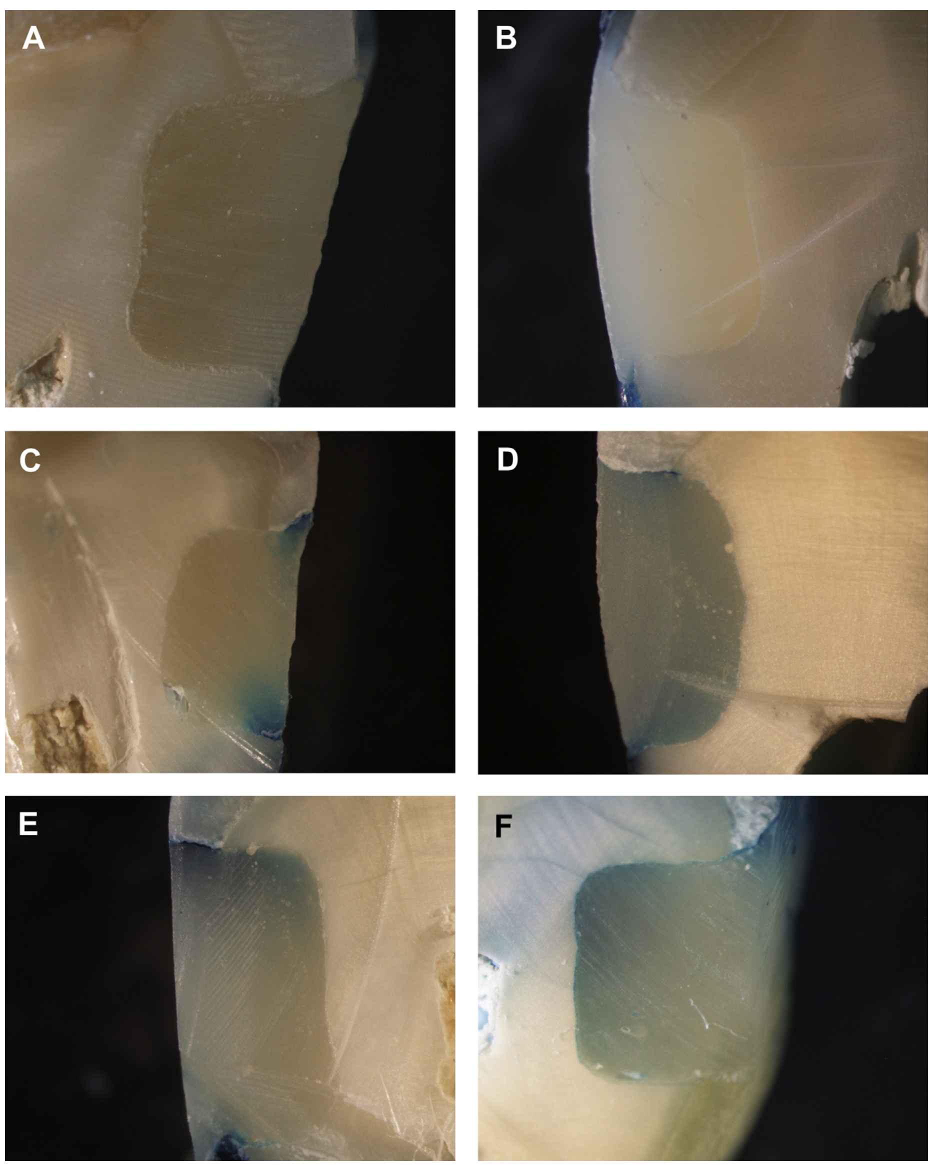

Figure 2 Illustrations of dye-penetration scores. (A) Score = 0; (B) score = 1; (C) score = 2; (D) score = 3; (E) score = 4; (F) score = 5.

Table 4 Dye penetration scores.

Score	Definition
0	No dye penetration at all
1	Dye penetration along the enamel bevel
2	Dye penetration up to 1/3 of the cavity wall
3	Dye penetration up to 2/3 of the cavity wall
4	Dye penetration to the cavity floor
5	Dye penetration of the cavity floor

In recent years, new cationic ring-opening monomer systems were investigated with the target of achieving a low-shrinking, highly reactive, and biocompatible composite that withstands the aggressive oral environment. The low-shrinking composite is expected to be associated with better bonding and improved marginal sealability because it achieves a more-uniform stress distribution at the restorative composite–tooth interface.[8] Clinical problems are partially related to polymerization shrinkage, and thus low-shrinking matrix resins were developed to reduce microleakage by introducing a completely new chemical basis (a combination of siolaxanes and oxiranes).[9] It was stated that although a considerable amount of performance data are available for silorane-based materials, information on microleakage is limited.[10] In this study, we evaluated the ring-opening chemistry of silorane-based composite resin, which caused less microleakage compared to dimethacrylate-based composites.

In previous studies, the marginal integrity and microleakage of silorane-based restorative systems were reported to be superior to those of methacrylate-based restorative systems.[3,11,12] Krifka et al[10] reported that silorane-based composite resin had the lowest dye penetration, but neither flowable nor conventional methacrylate-based composite resins provided better sealing abilities in their studies. Bagis et al[13] compared the marginal integrity of methacrylate- and silorane-based composite resins in wide (occlusal dimension being two-thirds of the intercuspal dimension) MOD cavities and reported no dye penetration for Filtek Silorane restorations. Similarly, according to the results of our study, the lowest microleakage rates were recorded in the silorane composite groups compared to the methacrylate groups regardless of the different LCUs used.

According to the manufacturer of Filtek Silorane, to achieve good restorations, silorane-based composites should be used only with their own bonding agents. Meanwhile, using combinations of adhesives with methacrylate-based composite resins of different manufacturers is a common practice.[10,14] For this reason, the Silorane System adhesive was used with silorane-based composite resins, whereas Clearfil S^3 bond was used for the other dimethacrylate-based composite resins.

Ernst et al[15] stated that Clearfil S^3 bond did not show marginal staining or gaps at the enamel margins in their study that evaluated the marginal integrity of class V restorations after bonding with different all-in-one and two-step self-etching adhesives. To minimize factors that affect the marginal leakage rate, Clearfil S^3 bond was preferred because of its high bonding capability for groups of methacrylate resins. Pilo and Ben-Amar[16] compared the microleakage of three one-bottle and three multistep adhesives and reported that the adhesive of the silorane-based composite resin exhibited the lowest dye penetration. According to this finding, it was concluded that factors other than bond strength determine the amount of microleakage. Thus, the first null hypothesis that microleakage values of silorane-based composite resins would be lower than those of methacrylate composite resins was accepted.

In previous studies, cavity configurations and curing methods also influenced the marginal sealing ability and material properties.[8,17–19] The cavity configuration (factor *C*) is the ratio of the bonded surface area to the unbonded surface area.[20] Klautau et al[17] reported that silorane-based composite systems were least affected by changes in the *C*-factor and resulted in a statistically significant good marginal adaptation compared to methacrylate-based composite resins.

Since the introduction of LED sources by Mills[21] in 1995, several concerns about their efficiency for light curing of resin-based materials have arisen. Mills et al[22] stated that LED sources were capable of significantly greater depth of curing for three different types of composite resins than were halogen LCUs. Oberholzer et al[19] reported significantly less microleakage at the dentine–cementum interface when restorations were cured with an LED unit

Table 5 Mean, median range, and standard deviation (SD) of marginal leakage of the various groups.

Application	Mean ± SD	Median (minimum–maximum)	Difference[a]
Aelite Aesthetic Enamel, QTH	3.25 ± 1.29	3.5 (1–5)	a
Aelite Aesthetic Enamel, LED 550	2.75 ± 0.91	3 (1–4)	a
InTen-S, QTH	2.7 ± 1.13	3 (1–5)	a,b
Aelite Aesthetic Enamel, LED 1055	2.55 ± 0.94	3 (1–4)	a,b
InTen-S, LED 550	2.4 ± 1.43	2.5 (1–5)	a,b
Filtek Silorane, QTH	1.9 ± 1.12	2 (0–4)	b
InTen-S, LED 1055	1.85 ± 0.86	2 (1–4)	b
Filtek Silorane, LED 550	1.65 ± 0.93	2 (0–3)	b,c
Filtek Silorane, LED 1055	1 ± 0.79	1 (0–3)	c

LED = light-emitting diode; QTH = quartz–tungsten–halogen.
[a] Different letters indicate dissimilarity of groups ($P < 0.05$).

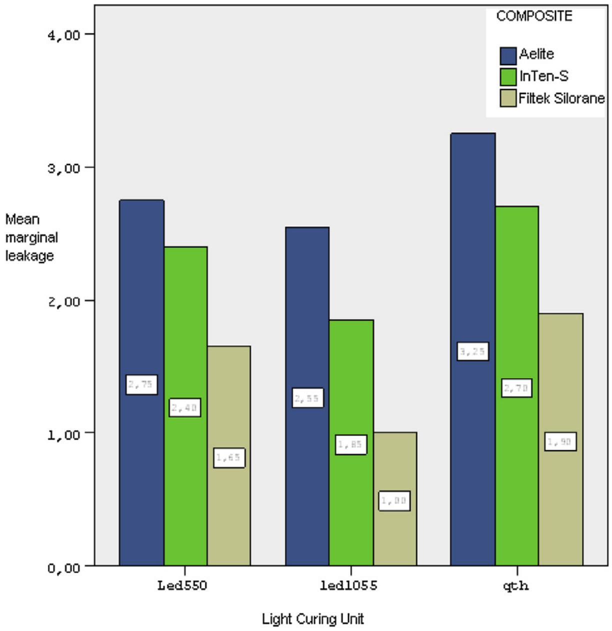

Figure 3 Graphic layout of the means and median ranges of marginal leakage of the various groups.

compared to curing with a standard halogen LCU. LED units with two different power outputs (LED 550 and LED 1055) and a QTH unit were used in this study.

In all tested composite resin groups, the lowest microleakage values were obtained with LED 1055 LCUs, and the highest were with QTH LCUs. Only in the silorane-based composite group did the LED 1055 show significantly lower microleakage scores than the QTH group, although having similar results to the LED 550 group. The LED 1055 unit used in this study delivered a much greater power density, suggesting a higher degree of polymerization. In this study, whereas the LED 1055 LCU was applied for 20 seconds, the LED 550 and QTH LCUs were applied for 40 seconds according to the manufacturers' recommendations. Soh et al[23] stated that the exposure duration was a determining factor of the polymerization quality of resin composites. In another study, Piva et al[24] reported that the use of LCUs with high output irradiance was preferable instead of increasing the exposure time to compensate for low output irradiances. The QTH LCU used in this study had a light output intensity (400 mW/cm^2), lower than those of the other LED LCUs (500 and 1300 mW/cm^2).

Although LED LCUs have a narrower spectral range (430—480 nm) than QTH LCUs (400—500 nm), LED LCUs have an emission spectrum similar to the absorption spectrum of the camphorquinone photoinitiator. This spectral homogeneity thus allows complete usage of the emitted light by LED LCUs, which does not occur with halogen curing.[25—27] This curing behavior could explain why silorane-based composites showed lower microleakage values with LED 1055 compared to QTH LCUs. This might have been due to the absorption spectrum of the camphorquinone photoinitiator present in Filtek Silorane and the matching emission spectrum of the LED 1055 LCU. The second null hypothesis that there would be no differences in microleakage values of composite resin restorations after polymerization with different LCUs was thus rejected.

It was concluded that the microleakage of the composite resin restorations varied according to the type of resin composite and the LCUs.

In this study, only one shade (A2) of composite was used, and the effects of different color shades were not considered. Within the limitations of the present study, it was concluded that it is not possible to entirely prevent microleakage, but it can be minimized with silorane-based composite resins and high-density output LED LCUs. The proper use of silorane will be very helpful for the clinical success of restorations.

References

1. Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. *Dent Mater* 2005;21:68—74.
2. Ilie N, Jelen E, Clementino-Luedemann T, Hickel R. Low-shrinkage composite for dental application. *Dent Mater J* 2007;26:149—55.
3. Eick JD, Kotha SP, Chappelow CC, et al. Properties of silorane-based dental resins and composites containing a stress-reducing monomer. *Dent Mater* 2007;23:1011—7.
4. Ferracane JL, Moser JB, Greener EH. Ultraviolet light-induced yellowing of dental restorative resins. *J Prosthet Dent* 1985;54:483—7.
5. Oesterle LJ, Newman SM, Shellhart WC. Rapid curing of bonding composite with a xenon plasma arc light. *Am J Orthod Dentofacial Orthop* 2001;119:610—6.
6. Nakamura S, Mukai T, Senoh M. Candela-class high-brightness InGan/AlGan double heterostructure blue light-emitting diodes. *Appl Physics Lett* 1994;64:1687—9.
7. Yap A, Stokes AN, Pearson GJ. An in vitro microleakage study of a new multi-purpose dental adhesive system. *J Oral Rehabil* 1996;23:302—8.
8. Ghulman MA. Effect of cavity configuration (C factor) on the marginal adaptation of low-shrinking composite: a comparative ex vivo study. *Int J Dent* 2011. http://dx.doi.org/10.1155/2011/159749.
9. Cadenaro M, Biasotto M, Scuor N, Breschi L, Davidson CL, Di Lenarda R. Assessment of polymerization contraction stress of three composite resins. *Dent Mater* 2008;24:681—5.
10. Krifka S, Federlin M, Hiller KA, Schmalz G. Microleakage of silorane- and methacrylate-based class V composite restorations. *Clin Oral Investig* 2012;16:1117—24.
11. Thalacker C, Heumann A, Weinmann W, Guggenberger R, Luchterhandt T, Syrek A. Marginal integrity of class V silorane and methacrylate composite restorations. *J Dent Res* 2004;83. [Abstract no:1364].
12. Palin WM, Fleming GJ, Nathwani H, Burke FJ, Randall RC. In vitro cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites. *Dent Mater*. 2005;21:324—35.
13. Bagis YH, Baltacioglu IH, Kahyaogulları S. Comparing microleakage and the layering methods of silorane-based resin composite in wide class II MOD cavities. *Oper Dent* 2009;34:578—85.
14. Thomsen KB, Peutzfeldt A. Resin composites: strength of the bond to dentin versus mechanical properties. *Clin Oral Investig* 2007;11:45—9.
15. Ernst CP, Galler P, Willershausen B, Haller B. Marginal integrity of class V restorations: SEM versus dye penetration. *Dent Mater* 2008;24:319—27.
16. Pilo R, Ben-Amar A. Comparison of microleakage for three one-bottle and three multiple-step dentine bonding agents. *J Prosthet Dent* 1999;82:209—13.
17. Klautau EB, Carneiro KK, Lobato MF, Machado SM, Silva e Souza Jr MH. Low shrinkage composite resins: influence on

sealing ability in unfavorable C-factor cavities. *Braz Oral Res* 2011;25:5—12.
18. Ozturk NA, Usumez A, Ozturk B, Usumez S. Influence of different light sources on microleakage of class V composite resin restorations. *J Oral Rehabil* 2004;31:500—4.
19. Oberholzer TG, Du Preez IC, Kidd M. Effect of LED curing on the microleakage, shear bond strength and surface hardness of a resin-based composite restoration. *Biomaterials* 2005;26: 3981—6.
20. Giachetti L, Scaminaci Russo D, Bambi C, Grandini R. A review of polymerization shrinkage stress: current techniques for posterior direct resin restorations. *J Contemp Dent Pract* 2006;7:79—88.
21. Mills R. Blue light emitting diodes—an alternative method of light curing? *Braz Dent J* 1995;178:169.
22. Mills RW, Jandt KD, Ashworth SH. Dental composite depth of cure with halogen and blue light emitting diode technology. *Br Dent J* 1999;186:388—91.
23. Soh MS, Yap AU, Siow KS. Effectiveness of composite cure associated with different curing modes of LED lights. *Oper Dent* 2003;28:371—7.
24. Piva E, Correr-Sobrinho L, Sinhoreti MA, Consani S, Demarco FF, Powers JM. Influence of energy density of different light sources on Knoop hardness of a dual-cured resin cement. *J Appl Oral Sci* 2008;16:189—93.
25. Hubbezoğlu I, Bolayir G, Doğan OM, Doğan A, Ozer A, Bek B. Microhardness evaluation of resin composites polymerized by three different light sources. *Dent Mater J* 2007;26: 845—53.
26. Yoon TH, Lee YK, Lim BS, Kim CW. Degree of polymerization of resin composites by different light sources. *J Oral Rehabil* 2002;29:1165—73.
27. Caughman WF, Rueggeberg FA, Curtis Jr JW. Clinical guidelines for photocuring restorative resins. *J Am Dent Assoc* 1995;126: 1280—6.